CAST IRON AND ITS RELATION TO MACHINE TOOLS

Paper presented to the Institution, Leicester and District Section, jointly with the Leicester Association of Engineers.

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FIRSTLY I wish to apologise for the scrappiness of this paper, as owing to war conditions I have been unable to give it the attention I should have liked, and certain experimental work that was in hand has not been completed. As, however, your secretary stressed to me the importance of being able to keep to your programme so far as local speakers were concerned, I will endeavour to do justice to this enormous subject. I am going to take full advantage of my title and treat the subject under two distinct headings: (1) Cast iron as a material for the construction of machine tools; (2) the working of cast iron upon machine tools.

I have been distinctly warned not to make this paper too metallurgical, but in order to make myself clear I must be permitted to give an account of the basic metallurgical facts.

Ordinary cast iron can be regarded as steel broken up by flakes of carbon, called graphite. But this steel may be of any quality from the almost carbon free dead mild type, through the strongest or fully pearlitic type with carbon about 0.8%, to the hardest cast steel type containing free iron carbide. This latter may be present in large quantities and is the major constituent of hard white iron.

When the groundwork of cast iron consists entirely of pearlite, which occurs with a combined carbon content of .6 to .9%, this groundwork is in its strongest condition and is also most responsive to heat treatment.

So much for the metallurgical aspect, which is not quite so simple as I have stated, and I must ask you to keep these few facts in mind.

Cast Iron as a Material for the Construction of Machine Tools.

Cast iron is the traditional material for the main constructional parts of machine tools for the following reasons: (1) Ease of casting into fairly intricate shapes; (2) low cost, compared to other materials; (3) rigidity; (4) reasonable resistance to wear, including its self-lubricating property owing to the presence of graphite and the penetration of oil into the graphite.

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The introduction of high-speed tool steels, and still more the introduction of tungsten carbide tools, has created a whole new set of problems in machine tool design. These can only be met in part by the alteration of design and improvement in materials. I, therefore, propose to discuss the physical properties of cast iron from the point of view of machine tool construction.

Strength and Rigidity.

Ultimate tensile strength is of little importance in most machines as the sections required to obtain a rigid machine are such that failure by fracture is rare except in accidental cases. The designer tries to keep his major stresses in cast iron compressive, but bending stresses are bound to occur. Thus, the ordinary transverse test as used for cast iron may be a more useful guide than the tensile test.

So much depends, however, in cast iron upon the tensile strength that I must discuss this first. Improvements in this property of cast iron have kept pace with the demands of machine tools. The old figure of 9 to 11 tons tensile which is quoted in most text books is out of date so far as machine tool irons are concerned. This is not so much because the demand has been for stronger irons as because of the demand for sounder irons which has resulted in an incidental increase in strength.

Class of cast iron	Tensile tons Sq. in.	Tran'se R.S. tons Sq. in.	Brinell hard'ss	Impact Ft. lbs.	Relative machin-ability
Light for guards	10	23	210	5	.08
Normal grade .	14	30	220	7	.08
Special grade .	18	33	230	9	.07
Ni-tensile ...	22	36	250	9	.07
Ni-tensile heat treated ...	28	36	320	9	.06
Ni-tensile + .5 Mo. H.Tr. ...	31	44	350	10	.04

TABLE I—MACHINE TOOL IRONS

Notes on Table 1.

Brinell hardness, 3,000 kg. load 10 m.m. ball. Impact, on special B.C.I.R.A. machine using unnotched bar, single blow. Bar 0.798 in. dia. Striking height, 1.3 in. Machineability, penetration inches per 100 revs. of Ardalloy tipped drill ½ in. dia. under 51-lb. load, tested on special A. Herbert machine.

It is now reasonable to demand that the iron for good machine tools should meet Grade I of B.S.S. 786 for high-duty cast iron, giving a range of 12½ to 15 tons per sq. in. tensile over the various sectional thicknesses. For the highest quality tools Grade II with tensile strength of 15 to 18 tons per sq. in. can fairly easily be met and should be sufficient to meet every demand except for parts carrying exceptional stresses. A third grade with tensiles of 18 to 20 tons per sq. in. is available for these cases in certain special types of cast iron such as Ni-Tensyl or the higher grades of Mechanite. Even higher strengths can be obtained by heat treating these materials. A typical range of machine tool irons with their physical properties is given in Table 1.

Much more important than tensile strength is the modulus of elasticity—i.e., the amount of "spring." Shaw describes "every machine tool a bundle of springs."

The modulus of elasticity of the material plays a great part in rigidity, the higher the modulus the less the deflection under a given load. For example, an iron having a modulus of elasticity of 20×10^6 will extend 1/1000th of an inch on a bar 10 in. long under a load of 2,000 lb., whilst one with a modulus of 10×10^6 will extend the same amount under half this load.

The modulus of elasticity in cast iron increases approximately as the tensile strength increases. Thus the tensile strength may be a useful guide. But the modulus does not increase in direct proportion to the tensile strength, and rises from 11×10^6 for the weakest irons to about 20×10^6 for the stronger irons[4]. In the higher strength irons the modulus varies considerably and irons developed particularly for tensile strength do not necessarily have the best modulus of elasticity values.

Whilst the modulus of elasticity has been increased so that demands may be met, this increase has tended to reduce the capacity of cast iron for damping out vibrations. Damping capacity is an important factor about which very little is known. Ordinary soft cast iron has a very good damping capacity whilst steel is poor. This is one of the major reasons why fabricated steel is not favoured for machine tools.

Such evidence as is available shows that the damping capacity of cast iron decreases as the tensile strength and modulus of elasticity increase. Thus, to obtain the rigidity necessary for the production of fine finish on parts being tooled, it is necessary to effect a compromise between the benefits obtained by a high modulus of elasticity and the corresponding increase in tendency to vibration. The presence of graphite seems to give cast iron its good damping capacity and this is one of the reasons why a very low graphite content is not desirable.

Resistance to Wear.

The other factor which the speeding up of machine tools has brought into the forefront is resistance to wear. Increased speeds and frequency of motion, combined with increased demand for accuracy have made this property of the utmost importance. Unfortunately resistance to wear is one of the most difficult things to measure as so many factors are variable. I will instance a few : (1) Lubrication ; (2) pressures ; (3) speeds ; (4) nature of opposing materials.

As previously stated, cast iron is reasonably good for resistance to wear of the type met with in the sliding parts of machine tools, owing to its being in fact a fairly high carbon steel broken up by graphite flakes. The graphite flakes act as a lubricant and a reservoir for the absorbtion of oil. The improvement in cast irons already noted have largely contributed to resistance to wear, particularly the improvement brought about by the change from the old soft type of cast iron to the harder " semi-steel " type, which really consists of the raising of the base of the cast iron from a mild steel to a high carbon steel, accompanied by a reduction in the size and quantity of graphite flakes. I am not convinced that the engineer's desire for a cast iron which has so little graphite that it is scarcely visible is really to the best advantage from the point of view of wear. Certainly, in the immediate post-war period, the reduction in graphite size and quantity indicated an improvement in quality, but this can be carried too far, and good wear resisting iron should not be too low in graphite.

The improvements in wear resistance offered by the normal improvements in cast iron are not sufficient, however, to meet the demands for the most exacting machines and further methods were evolved. One of the first of these was the densening of the important faces of the casting by placing in the mould an iron densener which increases the cooling rate of the metal, thus causing, locally, a higher combined carbon (i.e., a higher carbon in the steel groundwork) and a lower graphite content. This also enabled closer grained hard-wearing surfaces to be obtained on the " ways " of the casting than could normally be obtained. This is owing to the fact that these " ways " are usually of much heavier section than the rest of a casting, and the use of an iron to get the correct structure in these parts results in an unmachinable iron in the thinner parts.

Densening is still largely employed, and, provided that it is used intelligently and that the quality of the iron used is good and strictly controlled, it will meet the demands of the very largest proportion of machine tools. Objections are frequently raised that the use of denseners puts strains into a casting, which are relieved on machining, causing ultimate warpage. But it is my opinion that, provided that drastic densening is not necessary owing to the use of

a poor quality iron, densened castings warp less than undensened ones. The chief cause of warping in castings is the unequal rate of cooling of thick and thin parts, and if the cooling of the thick part is accelerated by densening, so that it more nearly approaches that of the thin parts, it is natural to assume that warpage will be reduced.

I have carefully used the word "densener" instead of "chill" although the latter is the word commonly used. A chill, strictly speaking, is a piece of iron cast against the mould of sufficient bulk to accelerate the cooling of the iron so drastically that the iron becomes white and unmachinable. Such an iron is very hard and resistant to abrasive wear but is not really suitable for machine tools, although attempts have been made to use it. Machining and warping problems are acute. The border line between densener and chill is very fine, and the foundryman who uses a densener that is just a little too heavy for the class of iron being poured, very soon finds himself in trouble with the machine shop owing to the appearance of hard spots and patches.

The next development in improving the wear of cast iron was by the use of alloying elements, particularly nickel and chromium. These alloys have two main effects when used in small quantities and in the right proportions: (1) They raise the hardness of the steel groundwork and thus give extra resistance to wear; (2) they even up the structure of the casting so that it is possible to use an iron which is initially harder without the risk of the formation of hard spots in the thinner sections.

The use of these irons (Ni. 1.0 to 2.0%, Cr. .3 to .6%) certainly improves the wear resistance of the iron considerably, but the objection to their use is in their cost, which becomes a major factor for large castings. It is not possible to alloy just that part of the casting, such as the shears of a lathe bed, without alloying the whole of the casting and the cost is proportionately high. Therefore, for large castings, it is usually sufficient to have a very high grade unalloyed iron, densened where necessary, and reserve the use of alloys for the smaller components, where the benefits can be better set off against the costs. I know that some manufacturers make a great point of the use of nickel cast iron in their machine tool beds and in cases of machines for very high speeds and frequencies of operations the cost may well be justified. It is claimed[1] that the extra costs can be offset by the reduced sections and sizes made possible by the use of stronger materials, but the necessity for rigidity and absence of vibration prevent full use being made of this, and sheer weight is often an important factor.

In the field of special and highly stressed parts alloy cast irons offer enormous opportunities. Firstly in strength—irons are available with strengths approaching that of mild steel, which if heat treated become as strong as mild steel, whilst having the charac-

teristics of rigidity, ease of casting, self lubrication, etc., associated with cast iron. It is important, however, to remember that owing to the presence of graphite flakes, these irons have practically no ductility.

For wear resistance, alloy cast irons are even more useful, particularly for cams. An ordinary alloy iron (nickel 1.5 chromium 0.5%) is very good, but the use of slightly higher nickel (2 to 3%) combined with hardening and tempering produces an excellent material. Such irons are machinable with a Brinell hardness of 250 to 300 as cast, even with ordinary milling cutters, and can be oil quenched from 850°C. with little variation of size to give a final hardness of 350 to 450°C. after tempering. In this condition the castings have to be ground, but the "shift" on hardening is frequently so small that grinding after hardening is unnecessary. The use of nickel improves the uniformity of hardness throughout the casting. Other uses of alloy cast irons include gears, clutch plates, gibs, tool slides, etc.

Hydraulically-operated Machines.

The development in the use of hydraulic power for the operation of machine tools has created a demand for castings which are pressure tight at very high pressures in spite of very intricate shapes and

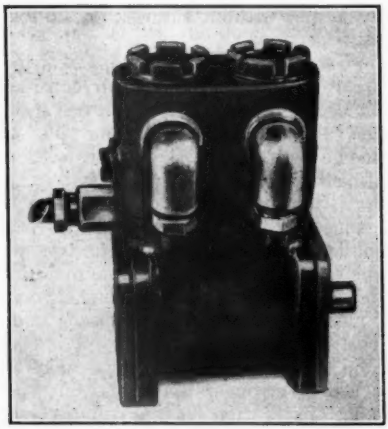

Fig. 1

rapidly changing sections. The use of alloy irons with their uniform sections, small graphite, and high strength is very frequently essential. Fig. 1 shows the valve gear, and Fig. 2 shows a group of cylin-

ders for hydraulically-operated sawing machines, tested to 1,400 lb. sq in. without any leakage.

Other methods of improving the " ways " of machine tool beds are constantly being tried out. Hardened wearing plates attached to the beds have been tried but gave great difficulty in obtaining the necessary rigid attachment. The latest development which is interesting machine tool manufacturers is the local hardening of the " ways " by flame-hardening. This process was developed in this country by Mr. Shorter and " shorterised " products are well known,

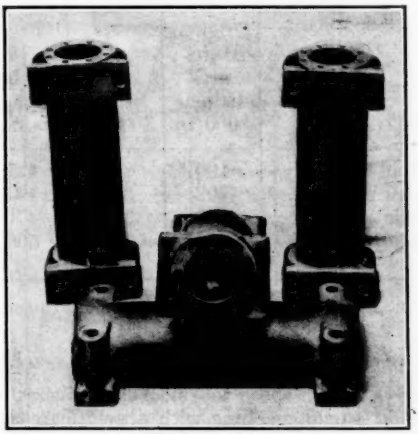

Fig. 2

but the adaption of this process to cast iron and particularly large castings such as lathe beds is quite recent. A good machine tool iron is suitable provided that the combined carbon (that is the carbon content of the steel groundwork) is at least .6%, although certain manufacturers claim that the presence of 1 to 1½% nickel is desirable. This is because nickel lowers the hardening temperature thus the treatment is less drastic.

My own experiments, given in Table 2, carried out in conjunction with the Shorter Process Company, show that a first-class machine tool iron of the 18-ton tensile grade gives results almost equal to the nickel cast iron. These bars were ground to 2 in. exact thickness and cleaned up after hardening to not less than 1/1000 in. under 2 in. The method of hardening is described in an article by P. A. Abe.

The Machining of Cast Iron

I am very hesitant about dealing with this aspect before a company of engineers and feel that I am putting my head into the lion's mouth. I do not pretend to have much knowledge of feeds and speeds, cutting angles, etc. One of the difficulties is in measuring machinability, which is nearly as difficult as measuring wear resistance. I have carried out certain experiments which I will deal with later, but unfortunately these were not finished owing to the war. Certain results appeared unusual and required repeat tests.

Material	Original Hardness Brinell 3000/10	Final Brinell 3000/10	Hardness Vickers Diamond	Rockwell C.
Normal M/C tool iron ...	190	269	437	42
Special M/C tool iron ...	192	363	491	44
1.5 Ni .5 Cr alloy iron ...	250	358	476	49
2.9 Ni .9 Cr. alloy iron ...	280	388	506	45

2 in. sq. Bars Treated by Shorter Process.

TABLE II

Before the days of high-speed tool steel the universal demand was for cast iron that would machine with absolute freedom, and the other properties of cast iron, when used for purposes involving any considerable machining, were entirely secondary, except in hydraulic work. The improvements that have been made in cast iron would not have been possible without the improvements that have been made in cutting tools. So that we find that as cast iron improved in strength and hardness, cutting tools became available that would deal with them. With the introduction of tungsten carbide tools no iron can really be called unmachinable. A white martensitic cast iron with a Brinell hardness of over 500 can be machined with the appropriate tool at 40 ft. per minute. Mr. H. H. Benny, of Alfred Herbert, Ltd., has carried out a good deal of work on this subject.

My own observations largely confirm his conclusions, but I do not agree that tensile strength is the main guide to machineability, particularly when cutting the modern innoculated irons. With these it is possible to use just the same cutting speeds as are used for good quality irons although the tensile strength is 50% greater. We regularly use for cutting Ni-Tensyl speeds of 150 ft. per min. with a

cut ¼ in. wide and a feed of 1/48 in., whilst finishing speeds can be taken up to 290 ft. per min. with a $^{1}/_{96}$ feed.

When using these high-cutting speeds the use of a machine tool that is rigid enough to stand up to the job is essential, and the figures given presume that such tools are available. Undoubtedly the best cast iron for cutting is an annealed iron and where the strength of the casting is not important this is the best material from a production point of view.

One of the most difficult problems in machining cast iron is milling, as tipped tools are not in frequent use. The speed of cut should be very closely watched.

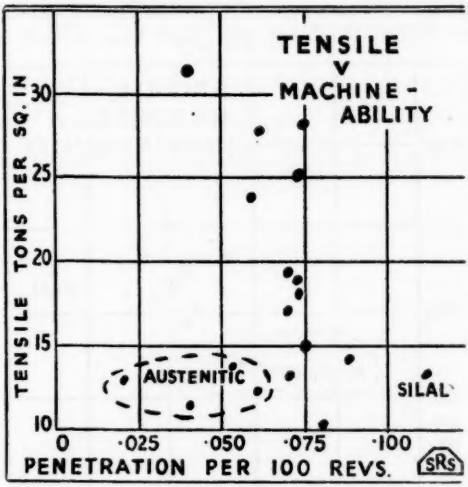

Fig. 3

I must include some reference to certain types of cast iron which have to be tooled, but which I have not mentioned so far, as they are not used in machine tool production. One of these is the austenitic type which demand very much slower cutting speeds and have the disadvantage of work-hardening as machining progresses. Cutting speeds for these should not exceed 80 ft. per minute and heavy cuts are preferred to light cuts. The castings should be annealed if they are under ½ in. thick and this annealing should be followed by quick cooling, preferably quenching in oil, to obtain a fully austenitic, and therefore machinable, structure. Then there is Silal—a special heat-resisting cast iron which is very easy to

machine owing to the complete absence of pearlite, except that it has a tendency to chill on thin corners. A normal anneal quickly restores full machinability. Ni-Hard, an iron with martensitic structure, in which the background is the same as that of a fully hardened steel, is best ground, but as indicated above it can be machined with tungsten carbide tools at very slow speeds. This has a limited use in machine tools, sometimes being used for centreless grinder rests.

A series of tests covering a wide range of cast irons has been carried out using the tungsten carbide tipped drill testing machine as used by Mr. Beeny. As before stated the results are not absolutely final. The figure for relative machinability is the depth of penetration of the drill per 100 revs. using a slow spiral drill $\frac{1}{2}$ in. dia. under a load of 51 lb. These results are plotted against tensile strength and against Brinell Hardness, and show that neither tensile nor

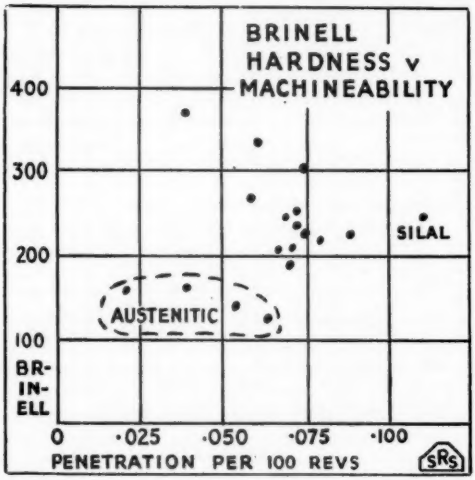

Fig. 4

Brinell is a true guide to machinability. The results for Silal are comparative with the machinability of annealed cast iron except that the Brinell would be about 160. The austenitic group cannot, of course, be considered with the others. This bears out a fact which is not sufficiently appreciated—that Brinell hardness only gives comparison of properties of similar materials.

Hard Spots.

Finally, occasional difficulties are experienced by engineers owing to hardness and unmachinability. I would explain that in his

endeavour to obtain the optimum properties from cast iron the ironfounder has to make his iron as hard as possible for the section concerned. If the iron is slightly harder than expected owing to some irregularity in the working of his melting plant, or to a quicker cooling rate than expected, owing to an isolated thin part or some extraneous cause, then free carbides appear and give machining troubles.

In conclusion I wish to thank Messrs. Alfred Herbert, Ltd., for carrying out the machinability tests, Messrs. Shorter Process, Ltd., for treating the flame-hardening samples, The British Cast Iron Research Association for the impact tests, The Mond Nickel Company, and others, for loan of slides.

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Discussion

MR. MARBROOK : I would like to ask Mr. Russell regarding the testing machine for hardness, whether he tried various pressures, because if that drill has not got the pressure for cutting, you do not obtain the same result with different materials. Also, whether he found out by varying the pressure he obtained different results ?

MR. RUSSELL : I have not carried out this test myself. I believe that Mr. Beeny tried various pressures. I expect he tried various pressures in his own experimental cast iron, and decided one was suitable. For the special types of cast iron the pressure used was not suitable.

MR. MARBROOK : Was it 50 lb. ?

MR. RUSSELL : 51 lb. Size of drill, $\frac{1}{8}$ in.

MR. MARBROOK : It looks rather small.

MR. RUSSELL : I do not doubt it.

MR. LEEDHAM : That was a lot proportioned pressure, wasn't it ?

MR. RUSSELL : I think the idea is to reduce the pressure on the tip as much as possible.

MR. COOKE : I should be glad if Mr. Russell could tell us just how the analysis of the material is controlled. As a designer, I have frequently specified a number of the materials that have been mentioned by Mr. Russell to-night, and have not infrequently got into trouble with the production people, who have said : " We have difficulty in machining this, cannot you change the specification ? " and who have produced spoiled cutters in support of their contention. Mr. Russell's statement that none of these irons are necessarily difficult to machine rather contradicts the experience of our own production people. One sees on the charts and specifications issued for general use certain percentages of nickel, etc., but they never contain any tolerances. I believe that the material analysis is fairly critical and it would be of interest to hear how it is controlled. I have heard of one foundry where pneumatic ducts have been installed connecting the foundry to the laboratory. By this means laboratory control is facilitated with the minimum delay. I wonder if Mr. Russell could perhaps amplify this a little.

There is another point. For a particular job, we have found it necessary to use an iron alloy having a very high nickel percentage for minimum expansion. We are having some difficulty in obtaining this. As a matter of fact, there only seems to be about two suppliers in the country. The nickel content is about 36%. I wonder whether you could explain the difficulties in producing this particular material, or whether it is that the majority of foundries are not really equipped for the production of such castings.

MR. RUSSELL: In control by analysis some margin is essential. Personally, I try, when I am drawing up a specification, to give a fairly wide tolerance within reasonable limits of experience, and as far as the alloy contents are concerned, particularly nickel, the margin is very wide, provided that you do not get above 2½%; that is, the iron is very sensitive to cooling rate with regard to its martensite changes. Nickel is quite mild in its action up to 2½%. Beyond that, the effect of nickel on cast iron is not really very clear, and it depends normally on section thicknesses. Take a casting only ¼ in. thick—if this has got more than 2½% nickel in it will be martensitic and unmachinable. To get a hard structure in a casting 2 in. thick, you require at least 4% of nickel. This is one of the large number of variables we have to contend with in the foundry.

The quick method of analysis control, to which Mr. Cooke refers, is out of reach of the average foundry. Our own method is control of raw materials, control of mixtures and, finally, analysis taking place after the castings have been made. If the analysis is wrong, then the castings have got to be withdrawn. All the types of casting to which Mr. Cooke is referring are rather thin compared with the average irons that are run in the same analysis, and there is a tendency towards these hard spots which I referred to in my lecture where the cooling rate is more than expected. Incidentally, the charts to which Mr. Cooke referred are drawn up rather from a theorectical point of view, and to my mind need the modifications of the practical foundryman.

Regarding the difficulty of obtaining castings for minimum expansion, it is difficult to draw the line when an iron casting becomes a nickel casting. An ordinary ironfounder has not got the melting plant capable of dealing with that type of metal. To be melted successfully, it is much more suitable for an alloy steels foundry than an alloy cast-iron foundry.

MR. PAVORD: Mr. Cooke has drawn attention to the design of castings. I would like to recall a recent experience, which brings in the designer, the foundry, the practical engineer, and the customer, also the value of helping one another. We will take three of the irons described in detail by Mr. Russell. The 10 to 12 tons per sq. in., 15 tons, and 22 to 23 tons, and used in the manufacture of a small press with table and upper movable beam about 40 in. long by 18 in. wide. The upper beam used to break when made from the 10 to 12 in. tons iron, due, generally, to overloading, or faulty castings and weak iron. This was dealt with by re-designing the upper beam and using the stronger iron 15 tons per sq. in., together with a safety pin arranged to shear off before the beam could break. It was found, however, that the customer, cutting gaskets for motor cylinder joints managed to break the beam before the pin sheared off. On request-

ing the return of beam and pin for investigation, it was found by micro-examination and physical test, that the pin was made of stronger material than the designer arranged for, and was being obtained by the customer himself from another source. The practical engineer, without altering the design of beam, had the material changed to the 22 to 23 tons per sq. in. The foundry was then able to increase the safety margin of castings with only a slightly increased cost. The customer now breaks safety pins, instead of press beams.

The designer to-day has a tremendous selection of materials to choose from, and can always vary his design to suit, and as our lecturer has shown, this is largely due to the great progress made in the foundry. I think we shall all agree that our foundries are doing very valuable research work, and combine it with a spirit of healthy consultation when in doubt about the thick and thin section.

Mr. Russell mentioned that Ni-Tensyl castings will give a uniform hardness all through the thickness. I am not sure whether he meant in the foundry cast condition, or after being heat-treated. If in the heat-treated condition it is advisable, if the heating and cooling have been done correctly, to temper at not less than 520°C., so as to break down the structure so that there are no hard areas or spots left that will give trouble in machining. At this stage the Brinell test is not a good guide, it will be about the same, if the casting were tempered to 490°C., but the machining will be very different. In many cases, the hardened steel pieces usually fitted on hard-wearing points can be omitted. Owing to the fine graphite, good lubrication properties are still maintained.

Mr. Russell has dealt with the Shorter process as applied to local heating and followed by cooling quickly with water on parts made from iron about the 15 tons per sq. in. quality. This gives a hard surface. With Ni-Tensyl material a cam, for instance, can be made and finished to size, and then heated to 850°C. to 870°C., quenched in oil, and tempered to 230°C. This treatment gives greater hardness than when tempered to 520°C., but not the same accuracy. For most purposes, however, the internal cam track would not distort sufficiently to matter.

MR. RUSSELL: I appreciate Mr. Pavord's contribution to the discussion and endorse the points raised. The use of nickel in giving uniform hardness is of value both for the "as cast" or "heat-treated" condition.

MR. CULLIN: I was particularly interested in two of the slides we have seen to-night. One was of a 2 in. square test bar, and the other a section of a lathe bed, both of which had been treated by this Shorter flame-hardening process. The thing that struck me was the apparent abruptness of the cut-off between the hardened surface and

the softer metal background. I should like to know whether the slides had been touched up to emphasise the hardened surface, or whether it is work developing the later extracted statement that one of those bars, or rather a casting, which had been flame-hardened, will break evenly right through without first breaking, or cracking, the hardened surface.

Secondly, since we are not in Coventry, at the moment, perhaps Mr. Russell will tell me what truth there is in the assertion that the metal used in the cylinder blocks of our mass-produced cars contains lead to permit of rapid machining?

MR. RUSSELL: The photographs of the flame-hardened test bar were entirely untouched. If you had got a microscope specimen you would see that it was a gradual transcision not a sudden line, and I personally broke one of those test bars in a testing machine to see whether the strength was affected, and the strength of the casting was not reduced, and there was no splitting off of the hardened face. When you break a case-hardened steel bar, the case does not break in quite the same place as the rest of the bar, in any case you don't get the same effect at all on the flame-hardened test bars.

With regard to cylinder blocks, lead would be an extremely difficult thing to handle in conjunction with cast iron, owing to its low melting point. If we get lead, zinc, or tin in cast iron, it absolutely ruins the surface of the castings. I do not know how they could make a casting with the appearance of a cylinder block with any proportion of lead in it. In the effort to speed up the production of cars, the wear resistance may be sacrificed, and there was a period when cylinder blocks were definitely soft. I think most manufacturers are appreciating that point, and I should not consider it is true at present.

MR. PAVORD: Referring to the wear of the cast-iron cylinder blocks, it is claimed that aluminium pistons wear out the cast iron. Is that also the reason why, in the latest practice, pistons are coated with tin?

MR. RUSSELL: I am afraid that I have no information on that point.

MR. PAVORD: For the purpose of free machining, lead is used in steel with good results in place of high sulphur. Mr. Cullin mentioned that it is also used in motor cylinder blocks.

MR. RUSSELL: I am quite aware of the use of leads and steel. Can you get lead steel castings? I am very doubtful. The lead at that temperature is as fluid as water, and it will penetrate into the soft mould, and I do not think you can get castings.

MR. S. HIBBERT RUSSELL: Lead is extraordinarily difficult to alloy with any other metal. There is a somewhat parallel case where we use a high percentage of lead in an acid-resisting bronze. Many years ago we had a number of pump casings to make in this alloy,

and when moulding these castings we followed our usual practice of running the casting in the foot. When the first casting was removed from the mould, it was found that the foot consisted of almost pure lead, owing to the lead separating from the mixture of metal and sinking into the foot as it passed through the runner. We overcame this particular difficulty by distributing the runners all round the casting and by vigorous stirring of the ladle of metal. As lead is far heavier than any other commercial metal, and as it never appears to alloy with any other metal, it is a problem to imagine how it can be distributed so uniformly throughout a mass of steel, and from our point of view is a very interesting foundry problem.

MR. L. H. LEEDHAM: I find with modern alloy cast irons, that the quality of the castings themselves is by no means as good as the older grey cast iron. They seem particularly prone to sponginess, especially where the metal changes section rather rapidly; it seems particularly noticeable in the case of the nickel chrome irons. I would like Mr. Russell to say if I am wrong, in this statement generally. We know that nickel chrome in alloy steel does make the solution more viscous and it occurs to me that the same explanation might be tenable for alloy cast iron not following complicated mould shapes.

One more practical question which I think affects all of us, especially in these rather hurried days,—that is the question of stabilising, or ageing, castings. We want to get our jigs and tools, etc., into the factory as quickly as possible. There is no time to stand them outside in the open while the casting seasons, which is carried out in more leisurely days. It is a question of very considerable importance in these times. Is there any process to which castings might be subjected whereby we can obtain the benefits of ageing by a very short process? I was at the N.P.L. some time ago and I was told that there they have a process of stabilising their castings. Unfortunately, in the hurry of the moment I forgot to ask for fuller details. I have tried the simple experiment of putting the castings into an oven and bringing them up to about 400°F., followed by slow cooling, but whether it actually stabilises them I am not in a position to say.

MR. RUSSELL: I am very disappointed that you think Ni-Tensyl is a spongy material, as we claim that it is not. It is not a question of sponginess, as the foundryman understands it, so much as the fact that it has a very high shrinkage in passing from the liquid to the solid. You refer to viscosity, it is not quite so much that as in passing from liquid to solid, the reduction in volume is very considerable. In Ni-Tensyl that shrinkage is always localised, and if you get certain heavy bosses on thin castings where you cannot put a feeder on the top to give you extra liquid metal, then it does have a tendency at the root of that boss to tear part of the liquid. Then

you get almost a crack in the casting. You call it " sponginess," but as we understand it, that is not quite the same thing.

A lot depends on the proportion of things. You get a boss that is longer than its diameter, then the tendency is to find this trouble at the root of it. It is bigger in diameter than its length, then the tendency is for shrinkage to be on the top. For that reason, Ni-Tensyl castings are very frequently made without any feeders at all but with excess metal on top of heavy facings to take up the shrinkage. You saw that slide of a pump lift, which was tested to 500 lb. per sq. in., and there was no leaking at all, and that is got by large feeders on top of the castings.

Regarding the question of ageing castings. I should advise you to put them in an oven and heat up as you suggest. I have carried it out on cast-iron rings, several feet diameter and find it effective.

MR. S. H. RUSSELL: I am afraid that as far as cast iron is concerned the bulk of the work is not done by ourselves, but by the engineers after the cast iron has been machined. I would insist that it is essential that the atmosphere of the furnace should be a neutral one, or at any rate not an oxidizing atmosphere, particularly with cast iron. I note that you say that variable hardness is obtained by the use of different methods of heating. You have carried your experimental work rather further than I have ever gone. The nature of the flame in the flame hardening process, so I believe, was originally gas, but is now being developed with oil. Your point with regard to the lead in cast iron as being a beneficial point of view for wear by reducing the surface tension is a good one. I was looking at lead, from the point of view of free machinery properties. I can see that it has potentialities in regard to the wear resistance. As to the form of graphite in cast iron, I know there are several modifications of graphite. It is an extremely difficult thing to study, there is a certain amount of work on it, but this has been rather above my head, I am afraid. Graphite in cast iron is, what I should call " black lead " ; it is the same sort of thing.

DR. GEO. SCHLESINGER (*in a written contribution*): The subject of Mr. Russell is exceedingly interesting for the machine tool designer and still more so for the production engineer in the machine tool factories.

The guidance surfaces of cast iron are the best with regard to wear and friction. The only exceptions are the guidances of hardened and ground steel which are difficult to make and, as mentioned by Mr. Russell, still more difficult to fasten solidly to the piece.

Modern practice is to make the surface dense by using better grades of components and not by using chills. The chilled plates are generally 10 to 12 in. long and they cannot be arranged so closely one against the other so that there do not remain dubious spaces which are not uniformly chilled, which results in warping

afterwards. The fitter knows how difficult it is—almost impossible—to get such irregular surfaces at rest. The damping effect is certainly of the greatest importance. There exist very thorough studies made by Professor Thum, Damstadt, published in the German periodicals " Stahl und Eisen " and Zeitschrift des Vereins Deutsche Ingeneure," during the course of the last ten years.

Regarding resistance to wear, it must be emphasised that, according to the existing publications, the best choice of the different hardness of two gliding surfaces would be to have the two components of the same hardness, maybe cylinder and piston, of a motor or, the carriage and bed of a lathe. Read the bibliography given in the article on " Hardness, Machinability and Resistance to Abrasion " in the Journal of the I.P.E., Vol. 16, No. 12, December, 1937. On pages 21 to 28 of this article the structure influence, the effect of chilling, the influence of the constituents of the alloys, the quality of the machine surface, the influence of the thickness of the wall are discussed, particularly in connection with cast-iron bodies of machine tools.

BIRMINGHAM SECTION ANNUAL SUPPER

THE Annual Supper of the Birmingham Section was held at the Farcroft Hotel, Handsworth, on Friday, March 15, 1940. The chair was occupied by Mr. H. C. R. Mullens, Managing Director of Wolseley Motors, Ltd., and the attendance numbered more than 130 members and visitors.

Messages of good-will were received from the President, Mr. Bailey, Lord Sempill, Deputy-President Viscount Nuffield, Lord Austin, Mr. James G. Young, Mr. W. M. W. Thomas, and the Section President, Mr. R. C. Fenton, who was indisposed.

The toast of " The King " was duly honoured.

MR. MULLENS, in proposing the toast of " The Institution," said : There is a German word which has been much in the news of late—the word " Ersatz "—a substitute ; and while I feel deeply honoured to have the privilege of proposing the toast of The Institution of Production Engineers, I confess that I, too, feel somewhat " ersatz." Because, as you know, I am really a substitute for Mr. W. M. W Thomas, who was to have addressed you to-night. Mr. Thomas, as I expect you have heard, has just been appointed Vice-Chairman of the Morris group of companies. I am sure you will appreciate what is meant by this sudden addition to his already considerable responsibilities. At the moment he is unable to fulfil his normal engagements, much as he would like to do so, and only this morning he was telling me how much he regretted not being able to be with you to-night. He has, therefore, asked me to come along to say, on his behalf, what I am sure he would say very much better.

It is now more than ten years since this Institution was formed. Ten years is not a very long time, judged by the older standards, but in these swift-moving days, much can happen in a decade—both good and bad. It can, for instance, witness the growth to power of the Nazi regime, or it can see the expansion of the Institution of Production Engineers to a membership of over 2,000.

But the true test lies in staying power. This Institution will, I feel confident, go on from strength to strength, whereas the other institution of which I have spoken will, with its President, probably disappear much more rapidly than it came into existence, and, may I suggest, that not a negligible contribution to its downfall, will be made by the production engineers of this country.

For this is a time, gentlemen, when the skill, the experience, the organising ability of the production engineer is of incomparable value. The position he holds in peace time is of high importance, but in time of war, and particularly a mechanised war, his training and knowledge are vital to the welfare and security of the nation.

It is, in particular, during the change-over from peace-time to war-time production that his special qualifications are so valuable. During such a change-over, problems arise which the lay mind cannot appreciate. In peace-time a motor-car factory, such as the one which I have the privilege of controlling, might produce eight types of car, but with very similiar production problems for each type. In war-time the same factory may be called on to make a hundred or more highly varied articles, some with a time cycle of many minutes, others with a time factor of less than ten seconds.

Experience gained in peace-time production, therefore, is not directly applicable to war work. Even if we go back to the last war we are little better off. As you all know, weapons and equipment, and the methods of producing them, have changed radically in the intervening years, so that whereas, in 1918, a shell fuse might take three minutes to produce, modern methods can turn out the same article in fifteen seconds.

At such a time, then, a high responsibility rests with the production engineer. He has to make and to purchase the right equipment for the job, to work out the time cycle required by vastly different products, taking into account the type of factory lay-out, and the plant available and then to design the necessary jigs and fixtures. In all these ways production engineers are daily rendering valuable service to the country, and it is at a time like the present that this Institution can be of the greatest importance. Through it, members can pool their skill and knowledge to the national advantage. For example, there have been instances of members working in different factories on the same article. By exchanging ideas they have been able to increase the efficiency and speed of their output to the national benefit.

I must not forget to mention the Institution's admirable Graduate and Student Sections, through which young men, not yet in positions of authority, and still undergoing training, may come in contact with older men with practical experience, and thus help to fit themselves for future responsibility.

I am also very pleased to note that your new Research Department, started by the generosity of Lord Nuffield with £25,000, is now running. Under your distinguished Director of Research, Dr. Schlesinger, together with his recently appointed assistant, Mr. Galloway, it is doing extremely valuable work.

In conclusion I congratulate you, Mr. President, and members, on the work which the Institution has done in its short but fruitful period of existence. May it enjoy continued success and honour in the future!

MR. J. D. SCAIFE, Past-President of the Institution, in replying to the toast, thanked Mr. Mullens for stressing the importance of the work of the production engineer and of the Institution during

these times of war. They carried a big responsibility and he believed that they were facing up to their task.

It was probably as a Past-President of the Institution that he had been invited to attend that gathering, but when he saw present so many members of that much-maligned industry, the machine tool trade, perhaps he had been asked to join them as one of the " forty thieves." As machine tool makers, they were rather in the black books of the production engineer at the moment over the vexed question of tests and alignments. It had been said that the customer was always right, but that did not apply in the present situation. This was a time when the production engineer had to take what he could get and be thankful. They were told that it was not for the customer just now to worry about price or quality. The controversy about tests and alignments showed, however, that the production engineer was not altogether satisfied to leave it at that.

Good progress was being made with regard to many of the important activities of their Institution. He was glad to say that on matters of educational policy and research they were drawing closer to their friends of the Institution of Mechanical Engineers. Dr. Schlesinger, as their Director of Research at Loughborough, was engaged on work in connection with surface finish and cutting tools that should prove of much value to the various engineering industries. They looked forward to the future with every confidence.

Mr. R. H. Youngash, in proposing the toast of " The Visitors," said he had been told it had become traditional for him to propose that toast. He did so with pleasure, for their visitors and guests were always people whom they were glad to welcome. Production engineers were very important people in this war and had to work hard, but he was one of those who considered that a little relaxation such as they were having that evening would relieve the strain on them and so do them good.

They had with them a number of old friends such as Mr. Scaife, Mr. Boyes, President of the Coventry Section, the General Secretary, Mr. Schofield and others. They also welcomed many new friends, headed by the Chairman, Mr. Mullens. Like Mr. Scaife, he was glad to see so many present from the machine tool industry who appeared quite unabashed by all the criticism heaped upon them. There was a very strict rule in their Institution against advertising. If a lecturer dared to show a lantern slide of a machine tool with the maker's name visible it was considered to be in bad taste. If it were not for that rule he might enthuse about many of the products made by their visitors and if he did, he might begin thus : Herbert's for chuckers ; Ward's for bars ; Archdale's for millers ; Wolseley's for cars.

But that would not be allowed, so he would not follow the subject further. This country is engaged in a life-and-death struggle, and

all of them are doing all that lies in their power to see that the means of victory are supplied to our fighting forces, and he was glad to know that The Institution as well as its individual members are taking a full share of the load.

MR. E. R. SCHOFIELD, who responded to the toast, said that as a member of the Institution from the Coventry Section, he was pleased to be with them. Production engineers were the king-pins of this war. The Institution was made up of a vigorous and enthusiastic body of men who would play no small part in winning the war. Production engineers had the knowledge, experience and ability to produce every kind of munition of war of the highest quality at the lowest possible price.

MR. G. WILLIAMS proposed the toast of "The Section President," and regretted that Mr. Fenton could not be with them because of indisposition. He was not going to say behind Mr. Fenton's back the things he would have said about him had he been present. Mr. Fenton had worked hard for the Institution and for the Birmingham Section, and they all hoped that he would soon be with them again.

MR. E. P. EDWARDS responded on behalf of Mr. Fenton.

Mr. I. H. Wright, Mr. E. W. Field, and Mr. F. C. White, Section Hon. Secretary, spoke briefly to other toasts.

PRODUCTION CONTROL FOR WIDELY VARYING PRODUCTS

Paper presented to the Institution, Coventry, Birmingham, and London Graduate Sections, by A. E. Riley, A.M.I. Mech.E., Grad. I.P.E.

BEFORE commencing the paper proper, I propose to consider production in its various forms, and to outline the type of production shop that we shall take as an example of varied production.

Types of Production.

Production can be conveniently sub-divided into three sections: Mass production, batch production, and jobbing production.

Mass Production.

Mass production may be defined as the manufacture, by specialised methods and repetitive processes, of standardised finished products in sufficient quantities to occupy the whole of a plant laid out for that purpose.

Mass production demands the sub-division and specialisation of plant, from top to bottom. The use of expensive tools and jigs for production, and accurate instruments for inspection, becomes a necessity. All parts must be interchangeable to avoid any delays in assembly, and the supplies of all materials must be perfectly synchronised. The maintenance of plant is a very important consideration, since any breakdown of great magnitude might have the effect of bringing the whole production shop to a standstill.

The outlay on special plant is usually so enormous that the production of new and improved designs is deterred until compelled by absolute sales necessity, or until other circumstances force prompt action. Thus mass production is inflexible. Some of the best examples of applied mass production are to be found in the automobile industry.

Batch Production.

Batch production may be defined as the intermittent manufacture of a large variety of products with the same plant. This type of production is usually adopted as a result of a limited demand for a standard range of products. Unless a continued demand is anti-

cipated for an article made by batch production, it is usual to spend as little as possible on tools. Thus, we find that batch production is far more flexible than mass production, and this flexibility is not only put to full use by the firm itself, but is usually taken for granted by the customer.

Jobbing Production.

Jobbing production may be defined as the manufacture of special products, designed and made to suit customers' requirements. With this type of production, almost every job is being rushed through the shop at once. Most of these special products have their complications, and consequently many emergencies arise in manufacture. Since orders are usually accepted for every job which the firm considers likely to yield sufficient profit, the importance of accurate estimates cannot be over-rated. The important thing to know in handling jobbing production is what is possible in each department and on each machine, and how long it will take.

Summary.

To sum up these three types of production, it has been estimated that 70% of the engineering works in this country are engaged in batch production, 3% in mass production, and the remainder in jobbing production.

The type of production shop which I am taking as an example of varied production is engaged in the manufacture of approximately 500 different products, the sales of which vary from six per year to 1,000 per year. Approximately 1,000 people are employed, the labour being graded to suit the requirements of the operation to be performed. For ease of control, the operators are divided into gangs, and the prices for work performed on any gang are based on an established gang rate. As regards materials, the firm has its own iron foundry, but all steel, in bar or upset form, together with all non-ferrous metals and proprietary articles, must be obtained from outside suppliers. This is a typical example of batch production, and our problem is to find an efficient method of controlling this production.

Of the three types batch production is probably the most difficult to control. With jobbing production there is always something definite to work at since most of the work is to the customer's special requirements and you know exactly what is wanted. There is very little chance of planning for future orders since they are such an unknown quantity. With mass production, the control is comparatively straightforward. The shop is planned to produce a certain quantity of the product per week, and the control of supplies is facilitated by a definite knowledge of what is required.

Production control for mass production can be sub-divided more satisfactorily than with any other type of production.

With batch production, future requirements are usually very uncertain. Most of the products are standard, and repeat orders may be expected for them, but the problem is, when will the repeat orders be placed, and for how many? Unless an attempt is made to anticipate future requirements and work put in hand in readiness, the deliveries are likely to suffer, which will mean a reduction in business. On the other hand, discretion must be used when the work is put in hand against future requirements, otherwise the work in progress will go up tremendously, and much work will be done only to be in stock for considerable periods. It is this uncertainty of the future requirements that makes batch production so difficult to control.

The most common method of controlling batch production is to issue an order for a quantity of a product to be made. Against this order the complete sets of parts are made in detail, and are finally fitted together as the finished product. This method has the disadvantage that no consideration is taken of the time required to make each individual item comprising the finished product. It is possible that on one finished product there is a small item which can be made in two weeks, whereas the item requiring the longest time takes six months to make. The orders for these parts would be placed at least six months before they were required by the fitter, and as these items are both ordered at the same time, it follows that one of them is ordered twenty-four weeks before it need have been.

Taking this collectively over the entire production shop, it will be seen that the unnecessary outlay in capital, in the form of excess work in progress, is enormous. Another disadvantage with this method of control is the direct replacement of all scrap. Since the order is for so many complete sets of parts, it is essential that these complete sets should be made up. If the batch is for 50 of the complete product, then 50 of each item have to be made, or 100 where the item occurs twice per set. When there is any scrap during the machining of these items, it has to be replaced on a scrap note so that by the time the item is complete it is possible that 40 are finished of the original quantity, followed by one's and two's being made on scrap notes. Scrap notes are a source of great expense, since the manufacture of small quantities is a waste of production. In addition to the factor of expense, scrap notes are undesirable because of the difficulty experienced in obtaining the full quantity of finished items for assembling. Difficulty is always experienced when asking a man on piecework to set up his machine for a small quantity, when the price has been based on a much larger quantity. It is often necessary to pay a man extra-work allowance to compensate for his having to set-up for a small quantity.

An attempt is sometimes made to counteract the effect of scrap notes by ordering more than are required to start with. A common practice is to add 10% on to the order to allow for scrap, thus where 50 of an item are required, 55 are ordered, and so on. This only partially remedies the trouble, and often, where the risk of scrap is very remote, large surplus stocks of some items soon accumulate. Another disadvantage is experienced with this method of control when sundry orders are received for spare parts. The parts in hand are all required for assembling and either an order must be placed to make some of the parts for this sundry order, or they must be taken from the main batch, which will be made up later.

With batch control, whilst consideration is given to the economical quantity for manufacturing the most important parts, it cannot be correct for all. Often 50 of a small part are made when by increasing the order to 100 they could have been made on an automatic machine at a considerable reduction in cost. Summing up, the batch method of controlling this varied production is expensive and unwieldy, and gives results which are far from satisfactory.

Before recommending a type of production control to meet this problem, I will define the production control department which will operate the scheme. The department includes planning, progress, and stores, all working under one central man. This man is responsible for the execution of orders from the time they are received until they are despatched.

The type of control which I recommend for controlling a varied production, is appropriately named " Individual piece part control." With this type of control, individual attention is given to every item of stock, comprising the whole range of finished products. By doing this, a supply of each item is maintained in the detail form, and when quantities of a finished product are required, a number of sets of parts for that product are issued from the stores to the fitting department for assembly. Thus, the fundamental factors to observe with this method of control, are : (*a*) That assemblies of the correct quantity are issued to the fitting department at the right time ; (*b*) that the supply of details in the stores for these assemblies should be maintained.

Maintaining the Detail Stock.

Since the production shop that we have taken as an example makes approximately 500 different finished products, it follows that there will be several thousand different items of stock, and if the stock of every one of these different items is to be independently maintained, it is obvious that individual attention must be given to the ordering of each item.

The first person to know if the stock is running low is the stores clerk, who marks off the issue of stock on the stores record card,

and sufficient information must be posted to the card to enable this man to decide whether it is time to re-order or not.

The stores record card gives: (*a*) The identification of the job and particulars of the product or products for which it is required; (*b*) particulars of the movement of stock showing the present stock balance; (*c*) particulars of all orders in progress against which quantities of the item are being made. Any scrap that occurs on the orders in progress is entered on the card to enable the stores clerk to know how many to expect off each order. This is essential as the scrap is not directly replaced with indivudal piece part control. If an order is placed on the shop for 200 of an article and 10 are scrapped on the first operation, five on the second operation, and three on the last operation, then the order is closed short at 182, 18 having been scrapped; (*d*) the data for re-ordering, which includes the minimum (stock plus progress) figure, economical batch quantity and the time required to produce that batch.

The minimum (stock plus progress) figure represents the quantity below which the combined stock and orders in progress should not fall. When this combined figure falls below the minimum, a batch, of the economical quantity shown on the card, is placed on the shop and completion asked for in the time specified.

It should be noted that although scrap is not directly replaced, particulars of the scrap are recorded for costing purposes. The effect of the scrap is counteracted by the fact that the (stock plus progress) figure on the stores record card falls below the minimum sooner than it would have done with no scrap, and consequently the item is re-ordered sooner.

To Fix a Minimum (Stock plus Progress) Figure.

Several important factors arise in fixing this minimum, the most important of which is probably the sales figure, which forms the basis of the calculations. In budgeting for future requirements the only practicable method is to work on past sales experience.

A representative period of time must be chosen for the sales figure. If the previous six months' sales are taken as a basis of calculation, any tendency there has been in the latter part of that period for the sales to increase or decrease is not very apparent. On the other hand, if the previous one month's sales are taken as a basis, then a temporary rise or fall of sales would easily lead to large errors in the subsequent calculations. It is necessary, therefore, to choose an intelligent mean, and a very suitable figure is three months' sales. The other factor affecting the minimum is the replacement time, which is comprised of the time required to obtain materials, and the time required for the machining of these materials. Thus, replacement time equals material time plus machining time.

Material Time.

In fixing the material times for items of stock, it is necessary to be familiar with the materials used and to know the sources of their supply. With the production shop we have taken as an example, we have divided the material into two main sections:

(1) *Cast iron.* The firm has its own foundry, where all the necessary cast iron jobs are made.

(2) *Other materials.* All steel, in bar or upset form, together with all non-ferrous metals and proprietary articles are obtained from outside suppliers.

It is a simple matter to compile a record of how long it takes to obtain the various materials. For cast iron work the foundry office would give the times required to obtain the castings, differentiating between the various classes of work, such as machine moulding, floor moulding, etc.

For the items obtained from outside suppliers, the information would have to be obtained from the buying department. The material record would look something like this:

MATERIAL LIST.

Cast Iron.	
Bar.	All standard sizes from stock.
Bar (special sizes).	One week.
Castings made on small moulding machines.	Three weeks.
Castings made on large moulding machines.	Two weeks.
Castings made on floor.	Four weeks.
Steel.	
Bar.	All standard list sizes from stock.
Bar (special sizes).	Two weeks.
Forgings and stampings.	Eight weeks.
Pressings.	Four weeks.
Aluminium and other Non-ferrous Materials.	
Bar or tube.	Two weeks.
Castings.	Six weeks.

Machining Time.

This is comprised of not only the time required to perform the various operations, but the time during which the job has to wait at a department before it can be put on the machine, due to the load of work on that department. The time required to inspect the work must also be allowed for.

An important factor deciding time required to machine will be the quantity made on each order. The fixing of the most economical batch quantity is very important, and is influenced by two fundamental points : (*a*) The larger the quantity being made on the order the cheaper the methods of manufacture that can be employed ; (*b*) the more often the firm's money can be turned over, the greater the advantage to the firm.

Thus again it is necessary to decide on an intelligent mean and very satisfactory results are obtained by fixing the economical batch quantity as near as possible to the three months' sales figure. There are always exceptions, of course, to every rule. On the one hand, three months' sales of a bulky item are sometimes too many to handle conveniently in the various departments at one time, in which case it becomes necessary to order a smaller quantity more frequently. On the other hand, there are cases where it is cheaper to make 50 than to make 12 of the same item, since by increasing the quantity to 50, an automatic operation, at a much cheaper rate, has been made possible.

When the economical quantity has been fixed, the machining time is calculated from the piece work prices and the known earning capacity of the various departments. This will be explained more fully later in the paper.

Having calculated the replacement time and added material time, the minimum is calculated as follows :—

If the three months' sales figure = 50, if the material time = ten weeks, and if the machining time = sixteen weeks, then the replacement time = ten plus sixteen = twenty-six weeks. And if 50 are sold in three months (thirteen weeks), then 100 are sold during the time that is required to get a batch through the shop. Thus, if the minimum was fixed at 100, then, in theory, just as the batch of finished articles was being delivered to the stores, the last of the stock would be despatched. The formula to work out this minimum would then be :—

$$\frac{A}{13} \times (B \text{ plus } C) = \text{minimum (stock plus progress).}$$

Where A = three months' sales, B = material time in weeks, C = machining time in weeks.

Whilst this arrangement would be alright in theory, in most cases it would be useless in practice, since it would leave no margin of safety to take care of such contingencies as sudden increases in sales, or excessive scrap. It is obvious, then, that a margin of safety must be allowed and by allowing a margin equivalent to three months' sales most contingencies can be taken care of.

This modifies the formula to :—

$$\frac{A}{13} \times (B \text{ plus } C) \text{ plus } A = \text{minimum (stock and progress)}$$

With the example quoted earlier, the minimum would be :—

$$\frac{50}{13} \times (10 \text{ plus } 16) \text{ plus } 50.$$

$$= \frac{50 \times 26}{13} \text{ plus } 50.$$

$$= 100 \text{ plus } 50.$$

$$= 150$$

Unless there was something special about the job, the economical batch quantity would be 50 (three months' sales figure), and this is what would happen in practice.

When the stock plus progress figure fell below 150, an order for 50 would be placed on the shop for completion in twenty-six weeks. After three months had elapsed this job would still be in progress, but 50 of the stock would have been despatched in the meantime, bringing the stock plus progress figure below the minimum again. Another batch of 50 would be placed on the shop for completion in twenty-six weeks, and so we should go on despatching 50 every three months and ordering 50 every three months, the minimum allowing sufficient time to replenish the stock, keeping a bit in hand against emergencies.

Returning to the stores record card, we see how the stores clerk has sufficient information to enable him to re-order the various items of stock at the right times. He sends a list of these orders to the planning department, telling them what he wants, how many he wants, and when he wants them by, and it is the duty of the planning department to make their own arrangements to see that he gets them by that time.

On receiving the list, which is sent in triplicate, a clerk in the planning department allocates an order number to each item. He then returns the second copy to the stores clerk who made out the order list, to enable the order number for each item to be entered on it's stores record card, and the third copy to the designs department. This keeps the designs department informed of work being ordered, thus enabling them to stop an order if they are contemplating a change in design on that item. The planning department copy is passed on to the man in charge of material ordering.

This man has not only to order the material for each item, but to follow the orders up and ensure their delivery on the dates specified. He should be familiar with the various materials used and their sources of supply. He should know the time required to obtain supplies of all materials, and if this time varies, due say to market conditions, then it is his duty to advise the person who controls the fixing of the minimum, in order that the necessary modifications can be made.

If iron castings are required an order is sent to the foundry office stating the quantity, pattern number, date required, and department to which the material must be sent. If stampings, etc., or proprietory articles are required, a requisition is made out to the buying department stating quantity, reference number, and department to which material must be sent.

All orders for material are entered in a follow-up file, in order of date required so that when that date is up, items not delivered can be urged. After the material has been ordered for each item on the list, the piece-work tickets for the process are applied for.

Piece-work Tickets.

The piece-work tickets are made out from master process cards which give operation sequence, instructions to operator, and piece-work price to be paid. They are made out in duplicate. Both copies contain all essential information, and on issue, are both stamped with the date of issue and the date for compietion in the appropriate spaces.

The payment copy is retained by the planning department for progress purposes whilst the operation is being performed. This is done by filing each chargehand's tickets separately, in datal order, thus enabling anyone to see at a glance how much work a chargehand has outstanding, and how much of that work is overdue. When the operation is completed the payment copy is used as a payment ticket in the correct sense of the word. The inspection copy is first issued to the chargehand, who sees all the necessary information. When the chargehand has completed his operation, he sends the work into the inspection department, with the inspection copy. Since the piece-work price of the operation is not the business of the inspector, the inspection copy is perforated to enable the chargehand to tear off the portion of the ticket containing the price. Thus the chargehand has a record of the price for the work performed which he can keep as a future check against payment.

A travel card is made out at the same time as the piece-work ticket. This travel card gives the individual instructions to each operator and to the inspector checking each operation. On receipt of the piece-work tickets, a progress card is made out. The piece-work tickets and travel card are then filed away in order number

order to await the delivery of the material. It is a definite advantage to keep the piece-work tickets away from the shop until they have the material to work on. No one wants to be bothered with a bundle of tickets for work which cannot be started due to the material not being available. When the material is delivered to the shop, a copy of the advice note is sent to the planning department, who immediately issue the piece-work tickets for the first operation, together with the travel card.

The inspection ticket goes out to the chargehand together with the travel card. The chargehand turns up the drawing specified on the ticket, and, working to the instructions on the travel card, completes his operation. He then tears off his portion of the ticket and sends the inspection half of the ticket, with the work, into the inspection department. The inspector checks the work and marks the inspection ticket accordingly. If the order was for 50 and he finds that three have been scrapped, he passes 47 and scraps three, giving the defective number of the department responsible for the scrap.

This inspection ticket is then sent to the planning department, who mark off the operation on the progress card. When the operation has been marked off, the next operation tickets are issued, the quantity this time being 47. A scrap note is made out for costing purposes giving the quantity of scrap and the amount of work performed on it. A copy of this note is sent to the stores clerk, who enters the scrap on the stores record card. The inspection ticket is then clipped to the payment ticket and passed through for payment. Whilst the inspector records the quantity passed, etc., on the inspection ticket, he also makes the same entry on the travel card and then the work is sent with the travel card to the next operation, and so this process repeats itself until all operations on the item have been completed and they are delivered to the stores. The order is closed at the quantity passed into stores.

Flexibility.

With a production shop engaged in varied production, one of the most essential features is flexibility, and the greater the flexibility the more uncertain becomes the programme to be carried out by the planning department. It is this uncertainty that makes it so extremely difficult to lay out schedules of work for each individual department very far in advance, in fact, there is not much to be gained by planning the work of any department until the work is issued to that department. This statement, no doubt, seems very unsound in theory, but in practice, if the schedules are made out well in advance, there are usually so many alterations to make in the programme that in the long run it resolves itself into the same thing as planning the work of each department at the time that the

work is issued to that department. This does not mean that no attempt is made to plan the work of a department. It is most essential that every department should work to a definite programme in order that the best results may be achieved by the shop as a whole.

The important thing in planning the production of a department is to know what is possible on each machine, and it's earning capacity. It is essential to know the earning capacity of the machine on which the operation is to be performed, because the only indication of the time required to complete the operation is given in terms of money.

If a machine can earn 15s. per day and a piece-work ticket is being issued for a job as follows: Quantity, 100; price, 1s. 3d.; preparation allowance, 2s. 6d.; then the value of the job is: 100 × 1s. 3d. plus 2s. 6d. = £6 7s. 6d., and at 15s. per day, eight and a half days will be required to complete the operation.

A complete record of the earning capacity of all the production units in the shop should be kept in the planning department. Every department should be analysed and sub-divided into it's various production units. Where there is more than one machine of a type, these should be grouped together, since the work to be performed on these machines is interchangeable.

Having established this sub-division of production units, each job should be processed to a definite machine, or group of similar machines, and then if this information is given on the piece-work tickets every time an order is issued, all the necessary information is available for planning the programme of each production unit. In arriving at the earning capacity of a department, it is far better to base the figure on actual earnings, than to calculate it from the gang rate and the number of hours worked per week. The latter method does not take into consideration the amount of bonus earned by the department in excess of the basic figure.

After calculating the machining time for an operation, there are two very important considerations: (a) Time during which the job is waiting on the department before being put on the machine; (b) time required for inspection. In allowing for these two times, the best method is to fix a time based on actual experience. It could be the result of an investigation taken over a period of, say, one month. The outcome of the investigation would perhaps be that with the planing department a waiting time of two weeks should be allowed, and an inspection time of two days, whereas with the grinding department, a waiting time of one week should be allowed and an inspection time of two days. It can be seen how, working along these lines, the machining time was estimated for the minimum calculations, and how the planning department receive an order the completion date of which is based on these calculations.

When the piece-work tickets are received, the process is entered

on the progress card. Then the time required for each operation is worked out from the values on the tickets according to the earning capacity of the particular machines on which the operations are to be performed. The completion date required has already been stipulated and by working back from the last operation with this date as a basis, the completion date for any one operation can be readily calculated. It is far better to leave the operation time in the form of so many days, than to fix actual dates, since any revision of the completion date would mean a revision of all the individual operation dates. When each operation is issued to the shop, the completion date for that operation is specified on the ticket, but, whilst it would be a very simple matter to fix this completion date from the progress card, as I have just shown, in practice it would soon lead to trouble, for with this type of production shop the work required is continually changing. Although the completion date is the result of calculation, and originally allows ample time to come through the shop, it might need revising as the result of an increase in sales. The balancing of plant is also a difficult matter, and with thoughtless dating we should soon find that one department was heavily overloaded, whilst another was short of work. This problem can be solved by using loading charts, which should be made out for each production unit in the shop.

In analysing the vertical milling department, we find that it can be divided into three loading units. There is one machine, the Herbert No. 28, which must be loaded separately, since all the large work must be done on that machine. The remaining five machines are all Herbert No. 16's, but only two of the five are fitted with circular attachments, so these must be loaded separately, all general milling requiring circular attachment being allocated to these two machines. The remaining three machines are loaded with all other general work.

In dating a ticket when issuing it to the shop, the two important factors are : (a) The completion date stipulated on the progress card ; (b) the load of work on the production unit in question. The loading chart is made out on graph paper to the scale of one square = 1s., and as a piece-work ticket is issued to a chargehand, so the value of that ticket is marked off on the loading chart.

If the machines are only partially loaded, then the full date is given, leaving room in the programme to fit in an urgent job, if necessary. If the machines are slightly overloaded the date is extended to suit this load, but if a department is heavily overloaded, then prompt action has to be taken, either to increase the earning capacity of the machines by arranging overtime, or to arrange for an alternative method of manufacture. The latter action should be avoided whenever possible since it usually means increased cost.

The Issue of Assemblies.

This is a most important section of the work under the individual piece-part scheme, since it will be appreciated that as all items are made on independent orders, there must be an order issued, at some time or other, to gather these parts together for building the finished product. A complete record of assembly lists is kept in the stores office, these lists being the exact copies of the lists of parts for the finished products, kept by the drawing office. These assembly lists are typed on paper which is suitable for blue print reproduction, so that when each assembly is issued the quantities can be marked on a blue print and sent to the fitting department with the parts, the master assembly list being retained in the stores office.

The starting point of an assembly order is the same as that of a detail order—i.e., the minimum of the stores record card. The fixing of the minimum for a finished product is fundamentally the same as fixing the minimum for a detail in that the sales figure and the replacement time are the factors of primary importance. In the case of the finished products, there is usually very little variation between the various replacement times, most of which would come comfortably within six weeks, so that by doubling this time, as a safeguard against such contingencies as a sudden rise in sales, it is quite satisfactory to fix the minimum for each finished product equal to the three months' sales figure. The economical batch quantity for assembling can also be fixed as near as possible to the three months' sales figure.

If there was a finished product with a three months' sales figure of 100, then the minimum on the stores record card would be 100. When the stock fell down to 99, an assembly would be issued to the fitter to build a further 100. The order would be issued in the same way as an order for a detail item. Piece-work tickets would be issued to the fitter, and the required number of sets of parts would be issued to him from the stores. If there was a shortage on any of the items, this would be reported to the progress department, giving not only the details of the shortage, but particulars of the orders from which the various items were to be supplied. An important point in connection with the assembly lists is the immediate notification of any alteration made by the drawing office. When an alteration to design is contemplated, an inventory should be taken of all the detail items comprising that finished product. These should then be balanced up, and orders placed only to preserve that balance.

The Work of the Progress Department.

Probably the best method of progressing varied production is to allocate certain departments to each of the progress men. Thus, progress man No. 1, might progress planing and milling, whilst pro-

gress man No. 2, would progress grinding, and so on. General progressing would be done from the payment copies of the piece-work tickets, which, it will be remembered, are divided into separate departments and filed in completion date order. Thus, taking the tickets of any department, all those filed before the current date represent jobs that are overdue. If the chargehand has not finished his operation by the completion date stipulated on his ticket, then the progress man must ascertain the reason, and take steps to put the matter right.

There are many reasons that are put forward from time to time for not completing work by the time stipulated. Sometimes it is a case of additional equipment required, in which case the progress man should urge the equipment through the proper channels, usually the tool service department. Sometimes it is a case of machine breakdown, in which case the progress man should report to the office, where notification should already have been received from the foreman of the department. The repairing of the machine would then be urged through the plant efficiency department. On other occasions the delay might be due to a difference of opinion between the chargehand and the inspector over quality, or between the chargehand and ratefixer over price. When these differences of opinion cannot be speedily settled by the two parties concerned, a decision should immediately be sought from the foreman, or if necessary, from the works manager.

The progress men would be under the supervision of a chief progress man, whose job it would be to co-ordinate their efforts. He would handle all the assembly shortage lists, and issue instructions to the different progress men regarding the items of shortage being machined in their departments.

To sum up the individual piece part method of control, we find that each item of stock is controlled independently. This control is effected by means of data on the stores record card which gives the three months' sales figure, the minimum, and the economical quantity for re-ordering. The whole of the stock commitments are based on this data. The factors which may effect the stock commitment by altering this data are :—

(1) An alteration in the time required to obtain materials. The production control department are immediately notified by the buyer of any alteration necessary in the times allowed to obtain materials.

(2) The machining time may alter due to the pressure of work in the various departments increasing. On the other hand, an improvement may be made in the method of manufacture which would show a reduction in machining time.

(3) Variation in the sales figure. This is the most common fluctuation and has to be watched carefully. With products of very low

sales a periodic check up is made, but with the products for which there is quite a steady demand a closer check is kept by keeping a sales chart. A typical sales chart will show the sales line plotted as the weekly sales figure over the previous three months. If the weekly sales themselves were plotted, the graph would be too eratic to serve any useful purpose, also, if too long a period was taken for averaging, the graph would be too flat. Thus, the sales are averaged over three months which gives a good idea of the sales trend. Against this sales figure, the production figure is plotted, also averaged over the previous three months, enabling a comparison to be made between sales and production. A line is also shown on the chart, representing the sales figure on the stores record card on which the calculations for the minima were based, so that by watching the sales movement week by week it is easy to decide when to alter the minima. It is more essential to alter the minima for a fall in sales, than for a rise in sales. With a fall in sales it would be easy to accumulate excessive stocks unless the minima were altered, whereas a rise in sales would be automatically taken care of by the fact that the frequency with which the orders were placed would be increased. If the sales continued to rise it would then be necessary to increase the minima. Working to the data on the stores record cards, orders are placed which the planning department execute by the date stipulated. Sets of parts are issued to the fitter for building into the finished products, which are then sent to stores to await sale.

The advantages of the individual piece part method of control over the batch method of control may be summarised as follows :—

(a) The elimination of the direct replacement of scrap. The replacement of scrap in small quantities is a very costly procedure and the piece part control shows a great saving in this direction.

(b) Individual attention can be given to each item so that the very best methods of manufacture can be taken advantage of.

(c) Since the orders for each item are not placed until absolutely necessary, instead of being placed all at the same time as in the batch system, the capital outlay in the form of work in progress is reduced to a minimum.

(d) In making items to supply against sundry orders for spares, these are included in the sales figure used as a basis of calculating, the minima consequently will be made in economical quantities without upsetting the batches of the finished products as is often the case with batch control.

The importance of close co-operation between the production control and other departments cannot be over estimated. No matter how thorough may be the work of the production control department it will be of no avail if other departments let them down. One of the most important departments in this respect is the plant efficiency department. The work of the production control department will

be dislocated if a breakdown or a stoppage of any kind occurs. The duties of the plant engineer in maintaining the means of production are vital in achieving the scheduled output of the factory. An attempt should be made, whenever possible, to anticipate the need for repairs, as this tends to preserve the continuity of production.

The foreman of each department should report any breakdown immediately it occurs to the plant efficiency department, and at the same time he should advise the production control department. Where this breakdown promises to affect seriously the planned programme, the production control department should immediately notify the works manager. It is not only breakdowns that affect production, for working conditions also play an important part. The efficiency of operators is undoubtedly affected by factory conditions, and lack of attention to defects in power, lighting, or heating, may involve serious consequences.

Transport is another service which often seriously affects production. The transport service should be organised intelligently, instead of running without a fixed objective. Inadequately planned, it will limit the productive capacity of the shop and the delays will add to the cost of production.

The connection between the production control department and the designs department is very important. Designs should be continually studied with a view to minimising the manufacturing difficulties, and standardised parts used whenever possible. A big fault to be found in many design offices connected with firms engaged in varied production, is a neglect of general standardisation. The production control department should notify the designs office immediately of any hold up in production connected with design.

The tool service is a department which has a tremendous influence on the efficiency of production. It is not only the suitability of design of the jigs and tools, but their timely manufacture, which so often affects the work of the production control department. When alterations to tools are found to be necessary, these should be effected without delay.

Difficulty is often experienced in dealing with the commercial departments, due chiefly to their different outlook, and lack of appreciation of the various difficulties which arise in production, but close co-operation with these departments should be facilitated by a common policy of service to the customer.

In conclusion, the secret of successful production control is the good organisation, not only of the department itself, but of the works in general. Organisation is something more than system, for whilst systems are of the utmost utility, they will not work themselves. We should guard against over-estimating the value of system and under-estimating the value of personality, for it is personality that contributes most to the general co-operation that makes the wheels go round.